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(54) **JETSPRAY NOZZLE AND METHOD FOR CLEANING PHOTO MASKS AND SEMICONDUCTOR WAFERS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 392 days.

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(57) **ABSTRACT**

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B08B 7/00 (2006.01)

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239/343, 368, 369–372

See application file for complete search history.

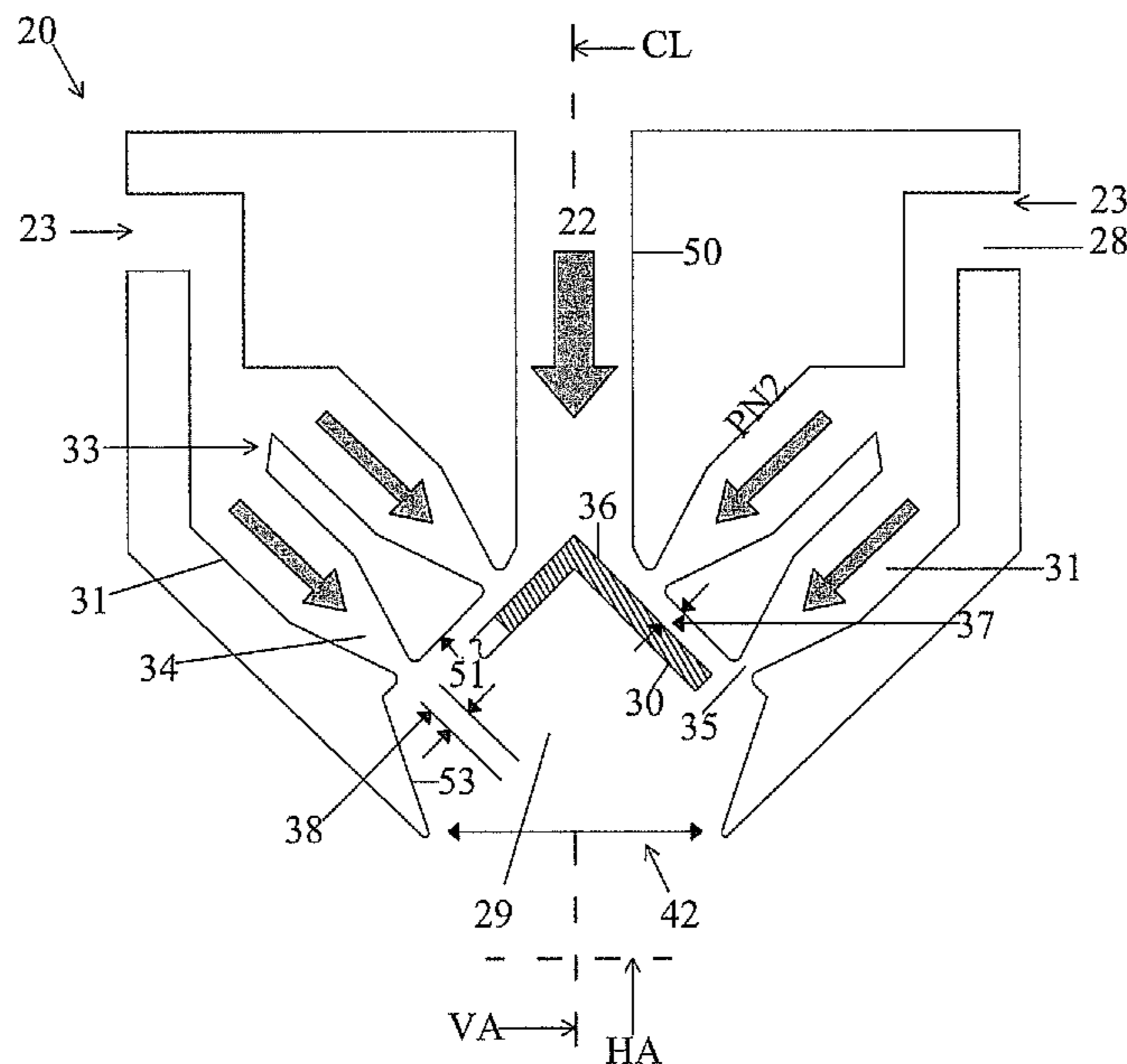
A jetspray nozzle for cleaning a photolithographic mask or semiconductor wafer and method for cleaning the same. The jetspray nozzle in one embodiment includes a water supply inlet, a gas supply inlet, a first row of gas injection nozzles communicating with the gas supply inlet, a mixing cavity defining a jetspray nozzle outlet, and a flow mixing baffle disposed in the cavity. The mixing baffle preferably is configured and arranged to combine gas and water in the jetspray nozzle for delivering a concentrated stream of gas with a cluster of micro water droplets entrained in the gas for removing contaminant particles from the mask. The jetspray nozzle is capable of cleaning photo masks or wafers without the use of chemicals. In one embodiment, the water may be deionized water and the gas may be nitrogen. In another embodiment, the jetspray nozzle further includes a second row of gas injection nozzles spaced above or below the first row of gas injection nozzles that communicate with the gas supply inlet.

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15 Claims, 8 Drawing Sheets



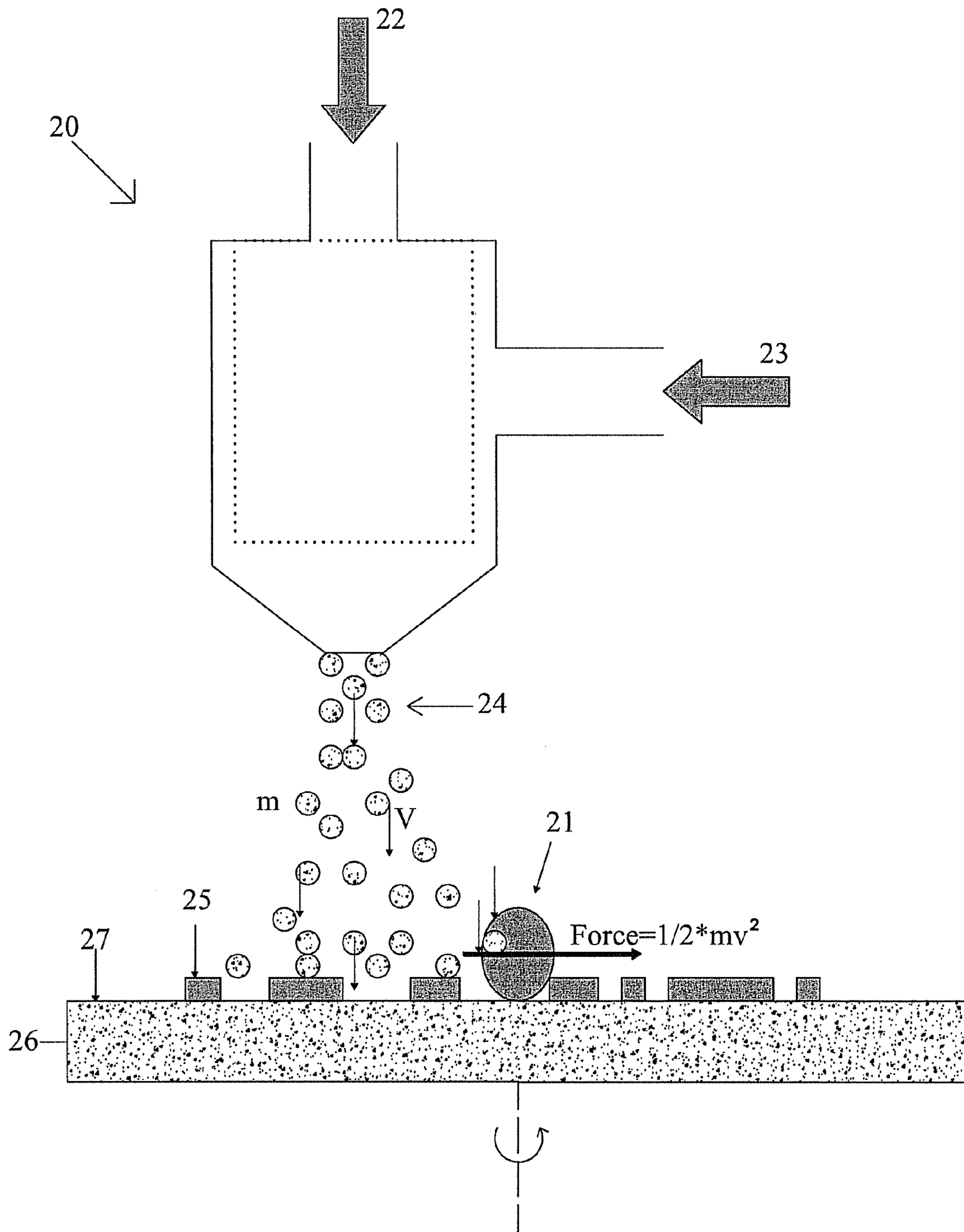


Fig.1

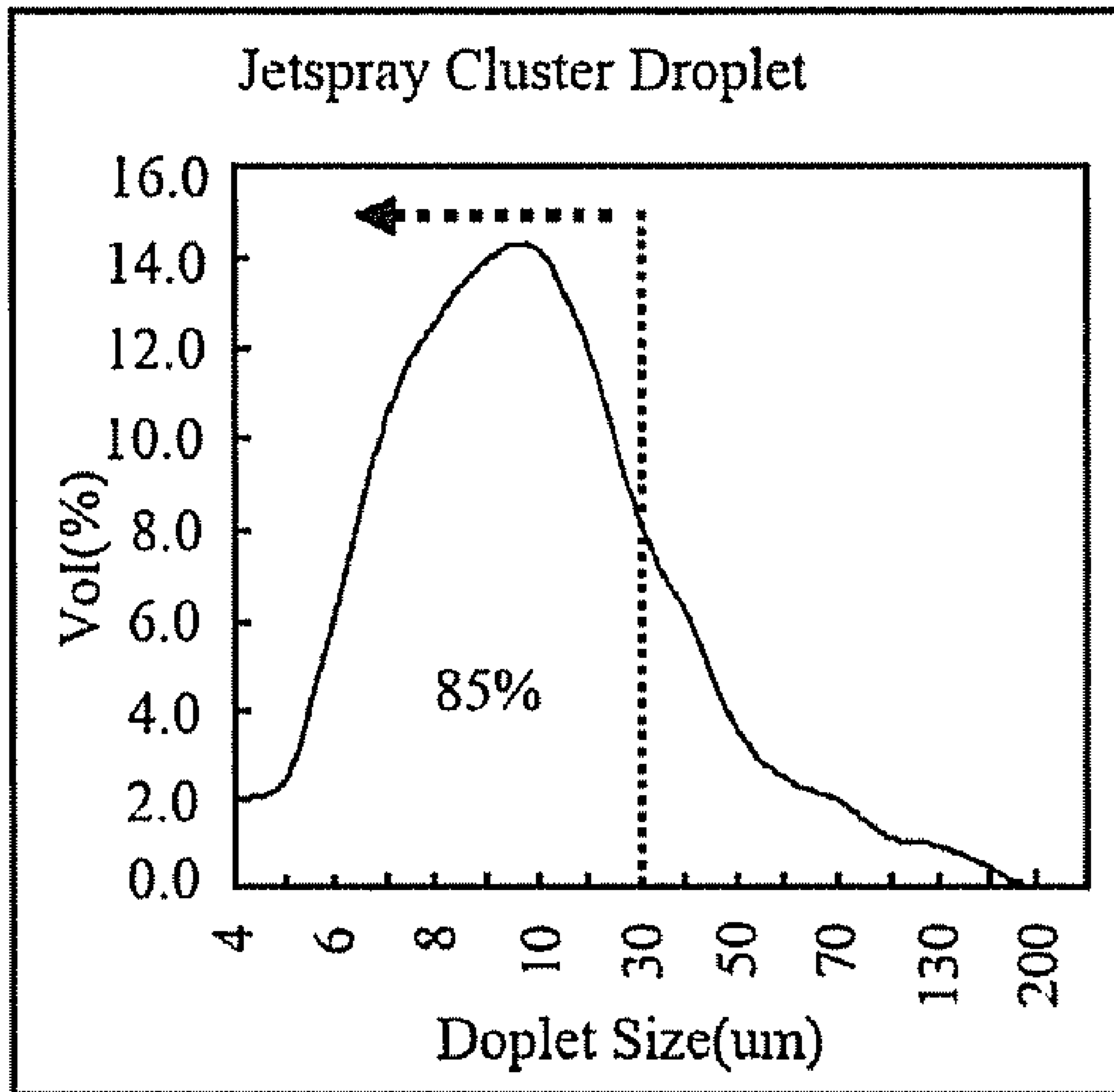


Fig.2

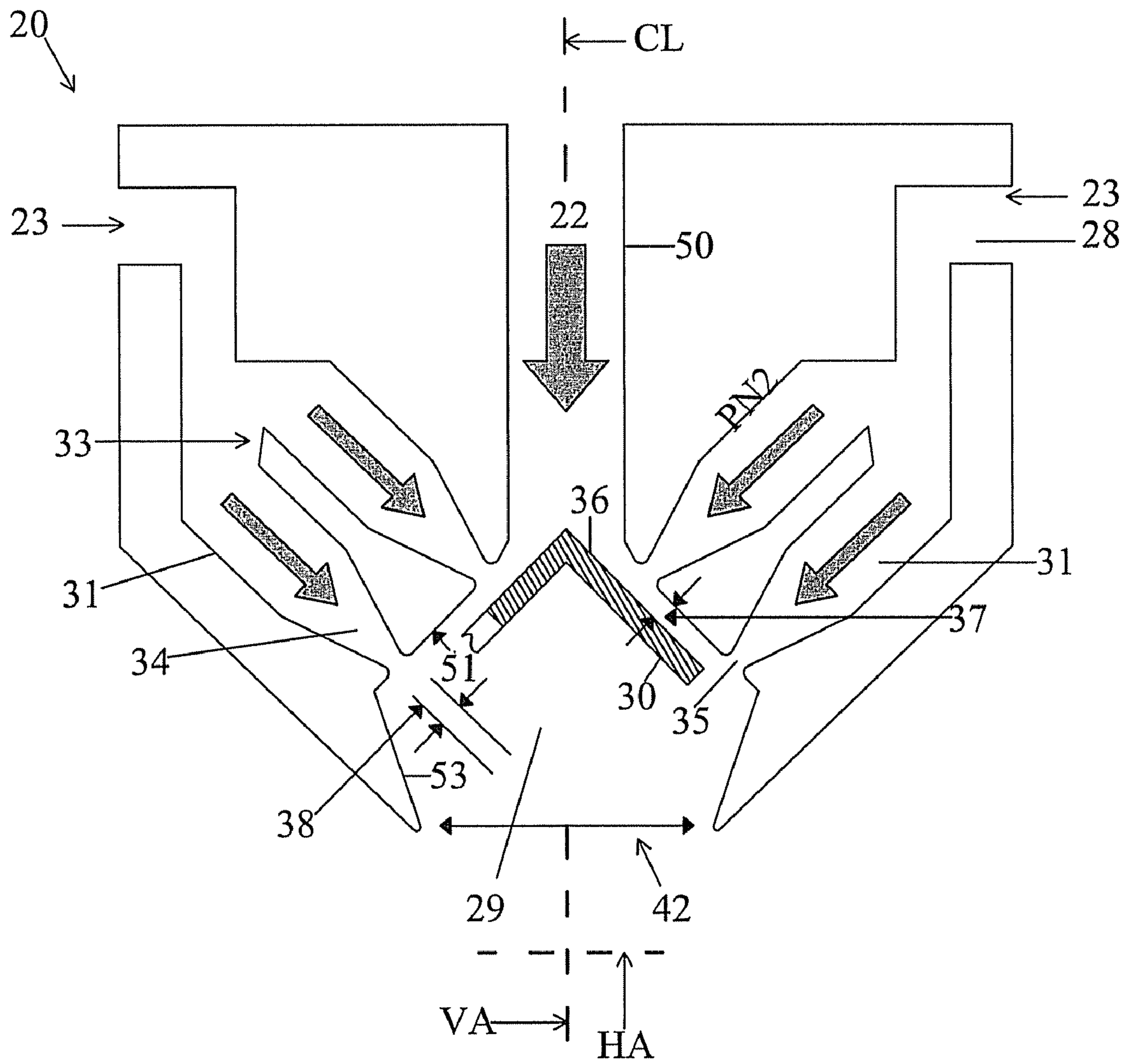


Fig.3

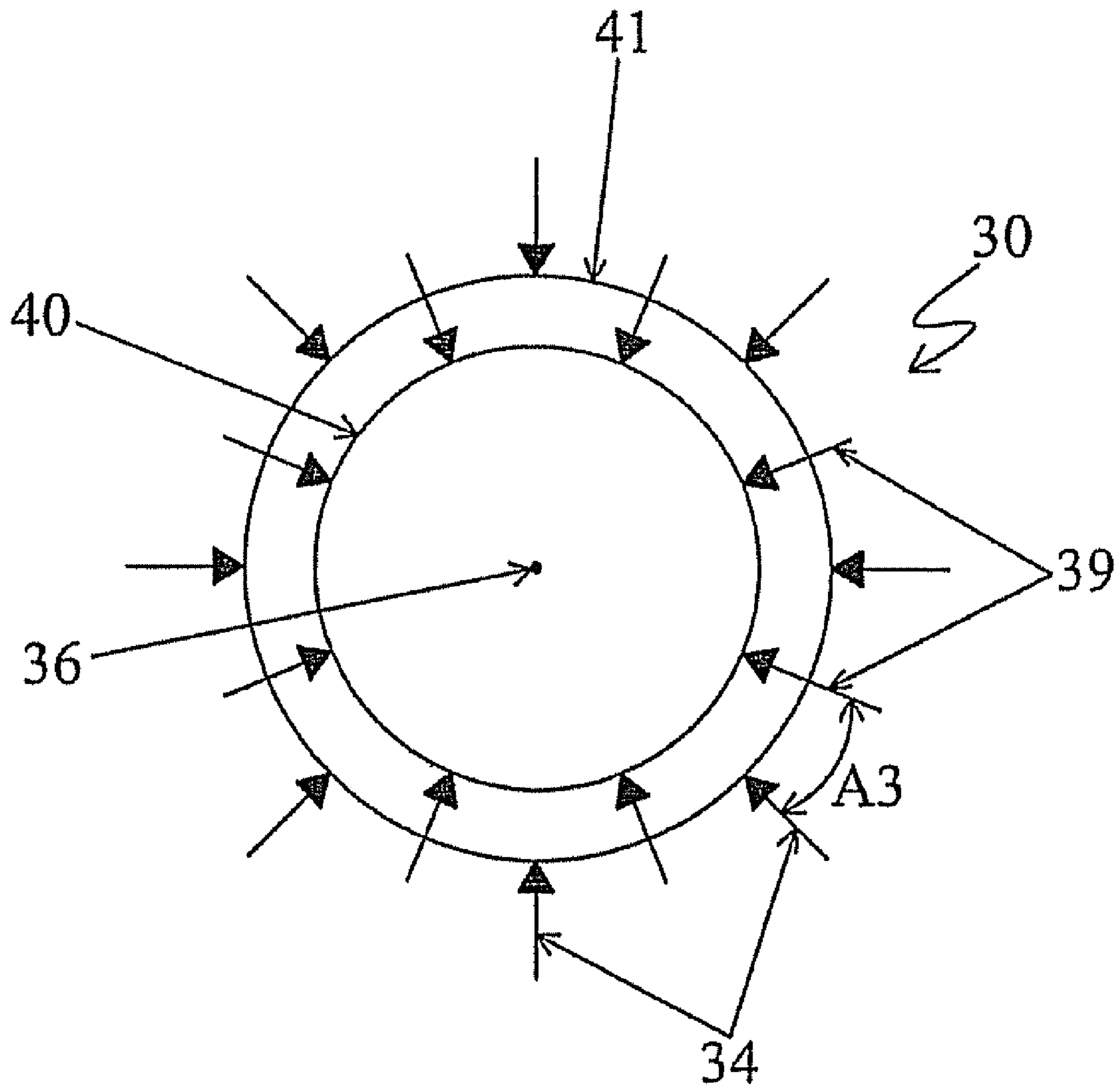


Fig.4

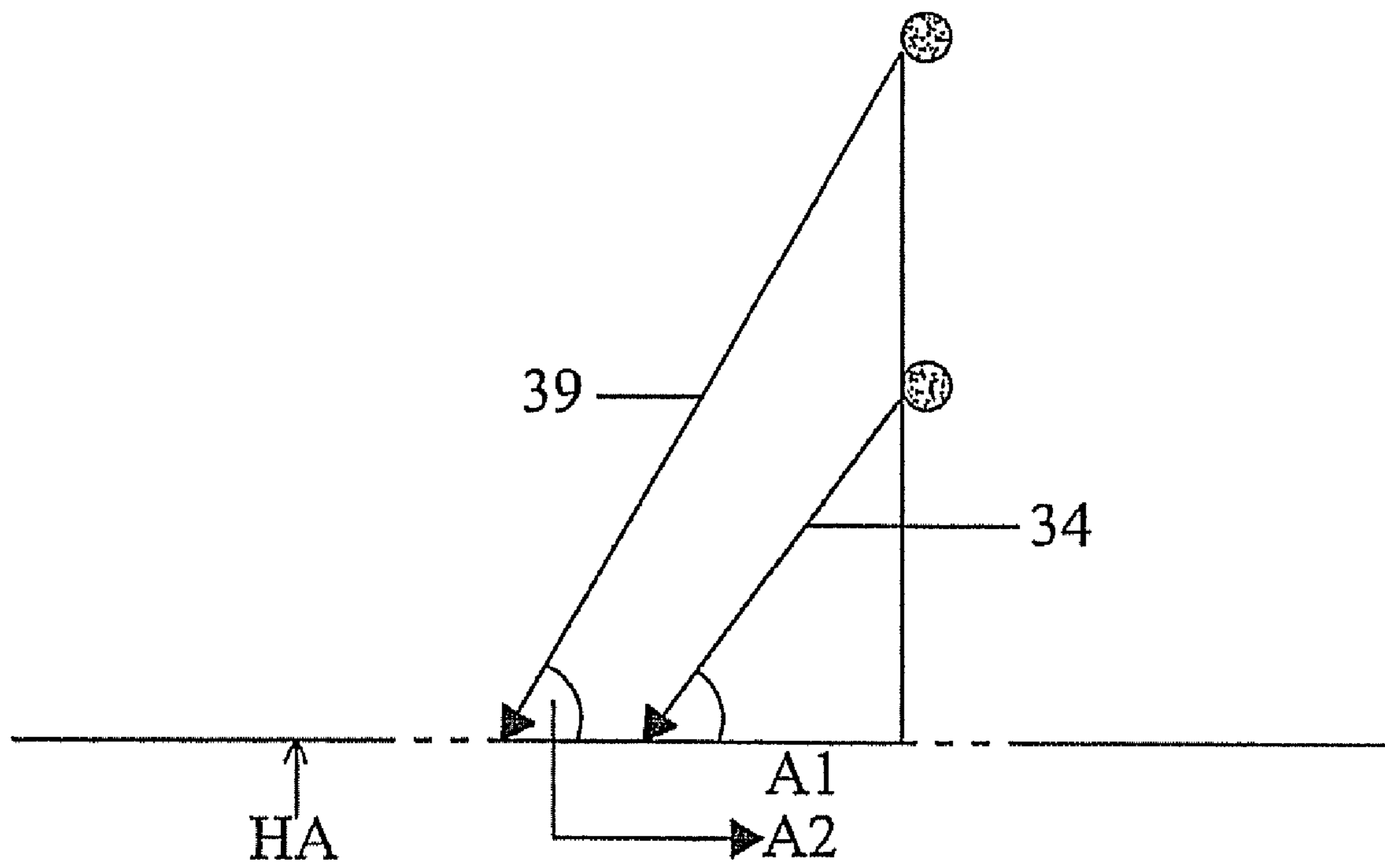


Fig.5

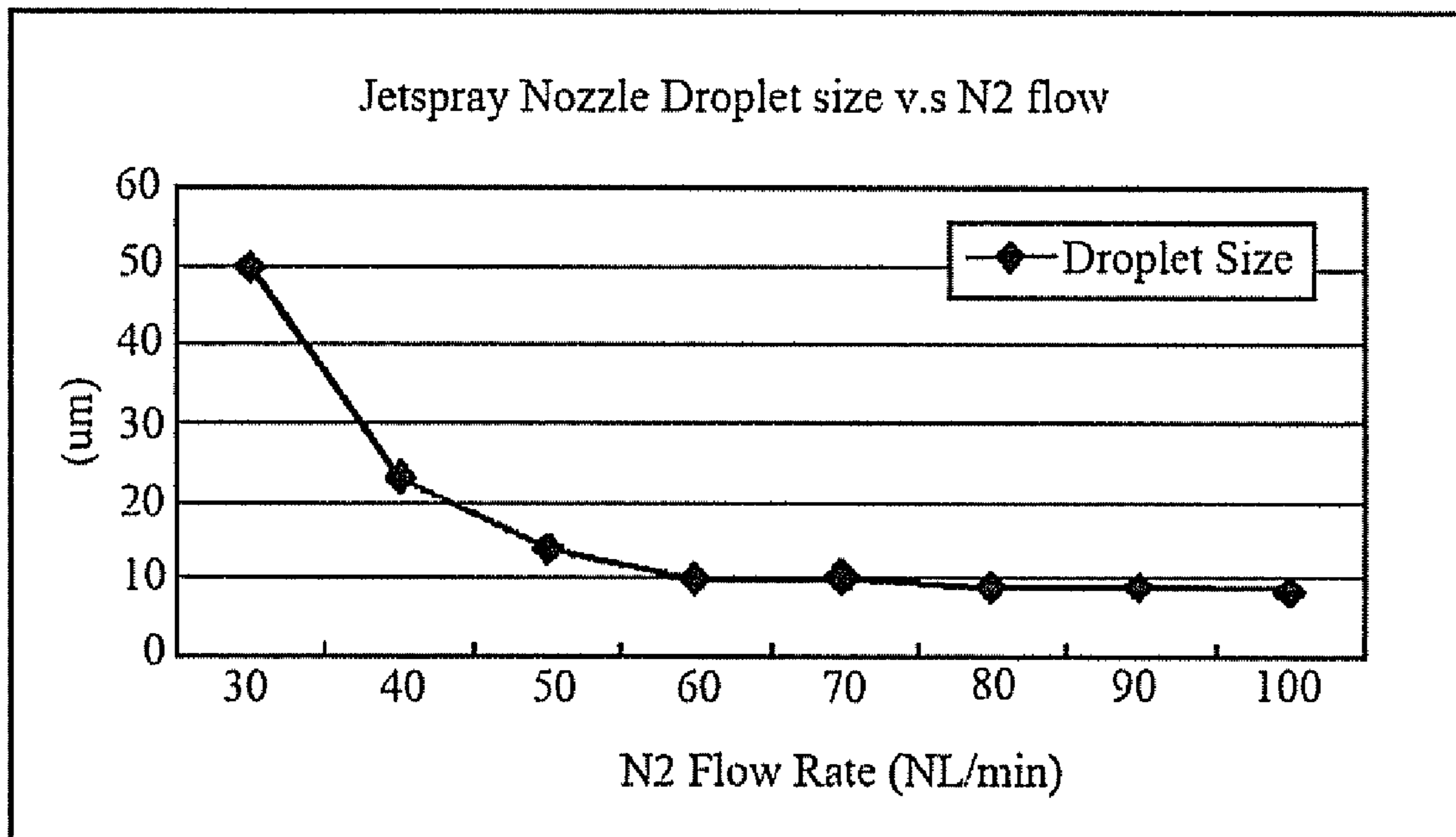


Fig.6

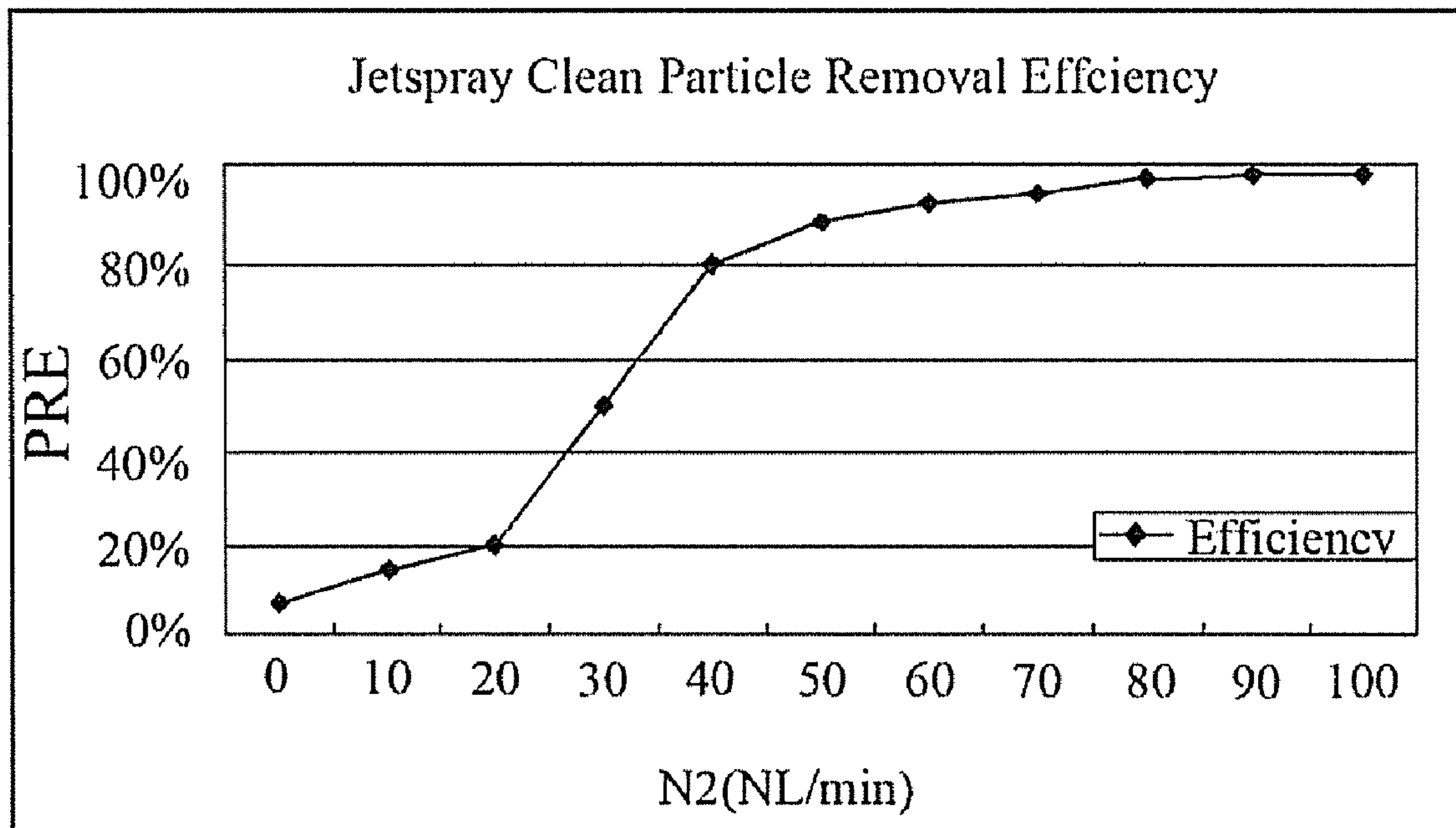


Fig.7

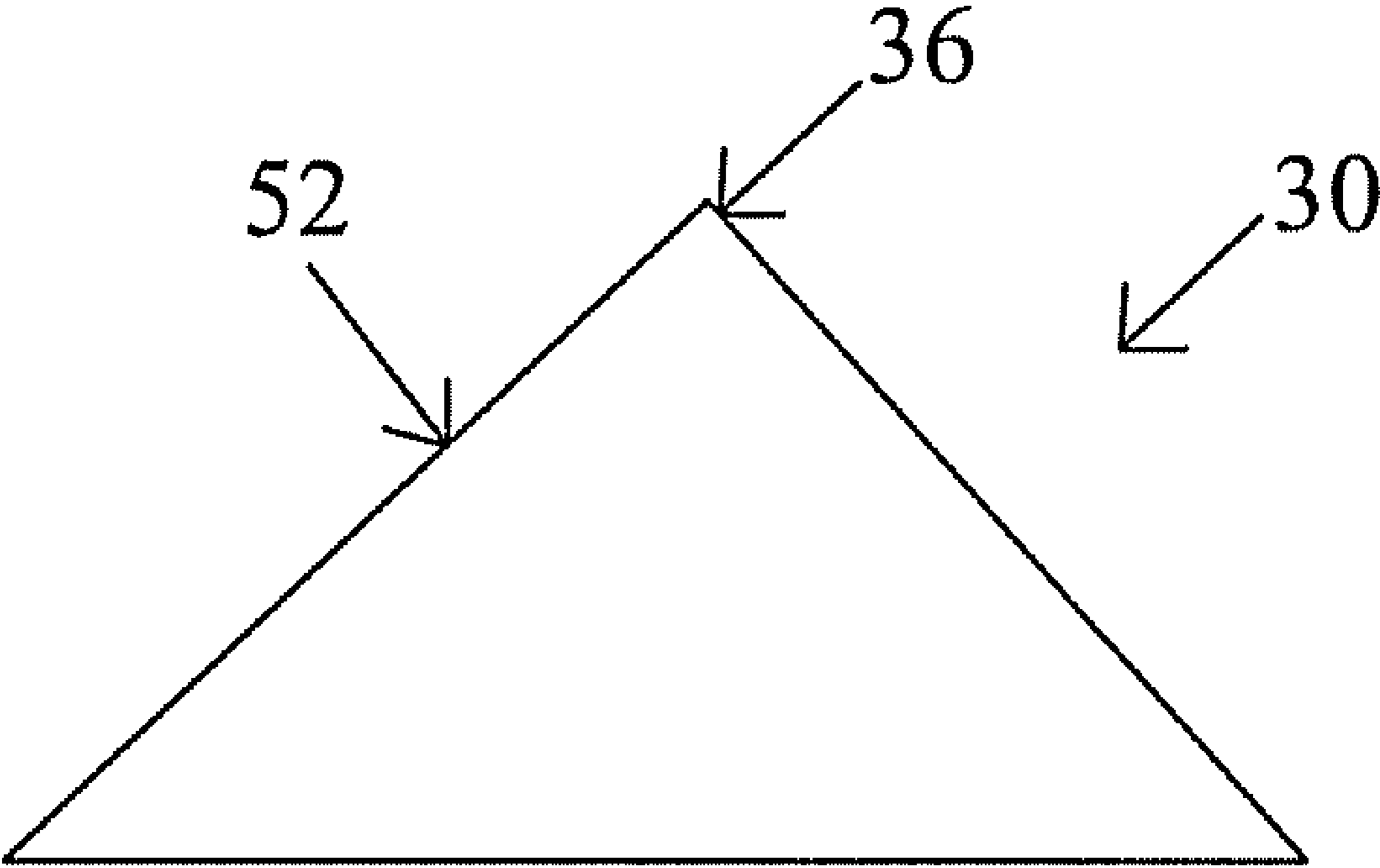


Fig.8

**JETSPRAY NOZZLE AND METHOD FOR
CLEANING PHOTO MASKS AND
SEMICONDUCTOR WAFERS**

FIELD OF THE INVENTION

The present invention generally relates semiconductors and reticles or photo masks used with photolithography processes for patterning semiconductors, and more particularly to apparatuses and methods for cleaning such photo masks or wafers.

BACKGROUND

Photolithography processes are used in semiconductor manufacture to pattern interconnect lines and other features for producing circuits on semiconductor wafer (substrate) surfaces. A conventional photolithography system generally includes components such as a light source, optical transmission and focusing elements, transparent reticles or photo masks, and process electronic controllers. The system is used to project a specific circuit or other feature image, defined by the mask reticle pattern, onto a semiconductor wafer coated with a light sensitive film (photoresist) coating. After image exposure, the film is then developed leaving the printed or other feature image of the circuit on the wafer.

Photo masks used today in semiconductor fabrication include conventional masks with a combination of circuit or other feature patterns formed by alternating transparent regions and opaque regions. Such photo masks typically consist of a substantially transparent base material such as quartz that allows the light to pass through certain regions with an opaque patterned layer having a desired circuit pattern formed thereon that prevents the light from passing through other certain regions. Materials such as chrome have been commonly used for forming the opaque layer and may typically have a thickness on the order of about 1,000 Angstrom. Other materials such as nickel and aluminum have also been used to form the patterned opaque layer on the surface of the photolithographic mask. Whereas conventional photo masks have a generally uniform thickness except for the very thin opaque chrome plated regions, phase shift masks or PSMs are photo masks in which certain regions of the transparent base material have different thicknesses. These latter "phase shift" regions cause a phase shift in the light traveling therethrough and minimize the effects of light diffraction through the photo mask for improved image resolution which may otherwise adversely affect formation of the intended pattern in the photoresist on the wafer. In some types of photo masks such as halftone phase shift masks, materials such as MoSiON has been used for the phase shifter material. In other instances, chromeless phase shift lithography (CPL) technology using chromeless masks have been used to the pattern the photoresist layer on the wafer.

As semiconductor fabrication technology advances to continually higher performing and smaller integrated circuit chips or dies, the accompanying circuits continue to become geometrically smaller and more densely packed on the chips. Accordingly, the pitch or spacing between circuit lines and other features formed on the wafer is concomitantly reduced.

Some problems associated with the shrinking circuit geometries found in the 90 nm and below semiconductor fabrication processes is contamination of the photo mask. As device features shrink, the minimum size threshold for surface contaminants that accumulate during use on the photo mask and which may adversely affect the photolithography process and proper patterning of the photoresist shrinks as

well. Particulate contamination on the photo mask may cause defective images to be printed onto the semiconductor wafer which can render an entire chip unusable.

Periodic cleaning of photo masks is therefore necessary to extend mask life time by removing accumulated particulate from the surface of the masks to avoid defective printing and circuit formation problems. Some conventional approaches to cleaning photo masks has been the use of wet chemical cleaning processes using ammonia-based solutions such as SC1/APM ($H_2O_2+NH_4OH+H_2O$), DIH₂/hydrogen water ($H_2O+H_2+NH_4OH$), and NGT (cluster H_2O +ammonia gas). Photo mask cleaning may be enhanced by using these solutions in combination with acoustical Megasonic cleaning processes in both dip type or spin type (i.e. ultrasonic waves with frequencies typically higher than 700 KHz, such as 1 MHz and 3 MHz) known in the semiconductor industry. In conventional dip mask cleaning processes, the photo mask is placed into the chemical solution typically contained in a tank. Megasonic waves are then generated within the solution to improve particulate removal from the photo mask.

The foregoing chemical cleaning of photo masks, however, has drawbacks. These known process may seriously damage the pattern (opaque layer features) or sub-resolution assist features (SRAF). After chemical cleaning, an additional step of rigorously rinsing the photo masks with water must be also performed to remove residual ammonia which can otherwise lead to the formation and growth of precipitated chemical defects on mask's chrome pattern that may cause circuit printing and formation problems during photolithography. Such rinsing operations, however, are not always completely effective in removing all residual ammonia. In addition, the chemical cleaning processes raises environmental issues by generating waste chemical solutions that require costly proper disposal and is inconsistent with current "green" manufacturing process goals.

An improved non-chemical photo mask cleaning process is desired.

SUMMARY

A specially-configured photolithographic mask cleaning jetspray nozzle and method for cleaning the same is provided that eliminates the use of chemical agents. In a preferred embodiment, the jetspray nozzle uses deionized water having a predetermined water droplet size produced by the nozzle which efficiently removes contaminants on the mask without damaging the opaque mask pattern or SRAF. In one embodiment, the preferred or target water droplet size is about 10 microns. According to another embodiment, the jetspray nozzle preferably produces a cluster of water droplets having a size distribution of 85% less than or equal to about 30 microns. According to another embodiment, the jetspray nozzle may also be used to clean semiconductor wafers as further described herein.

In one embodiment according to the present invention, a spin type mask cleaning process is advantageously used here. The photo mask is placed onto a controllable high speed rotational chuck. Around the chuck, many programmable controllable swivel arms may be used which are integrated with different type process nozzle heads (i.e. megasonic nozzle, Ozone water nozzle, Jetspray nozzle, etc.) for organic, inorganic & contaminant removal from the photo mask.

According to one embodiment of the present invention, a jetspray nozzle for cleaning a photolithographic mask or semiconductor wafer includes: a water supply inlet; a gas supply inlet; a first row of gas injection nozzles fluidly com-

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communicating with the gas supply inlet; a mixing cavity defining a jetspray nozzle outlet; and a flow mixing baffle disposed in the cavity. The mixing baffle is preferably configured and arranged to combine gas and water for delivering a gas-water mixture from the nozzle outlet for removing contaminant particles from the photo mask or semiconductor wafer. In another embodiment, the jetspray nozzle further includes a second row of gas injection nozzles spaced above or below the first row of gas injection nozzles and also fluidly communicating with the gas supply inlet. In one embodiment, the first and second rows of gas injection nozzles are arranged concentrically about a centerline of the nozzle. In a preferred embodiment, the flow mixing baffle may have a conical shape.

According to another embodiment of the present invention, a jetspray nozzle for cleaning a photolithographic mask or semiconductor wafer includes: a water supply inlet; a gas supply inlet; a first row of lower gas injection nozzles communicating with the gas supply inlet and being arranged concentrically about a centerline defined by the nozzle; a second row of upper gas injection nozzles communicating with the gas supply inlet and being arranged concentrically about the centerline of the nozzle; a mixing cavity defining a jetspray nozzle outlet; and a conical flow mixing baffle disposed in the cavity. The mixing baffle is preferably configured and arranged to combine gas and water for delivering a gas-water mixture from the nozzle outlet for removing contaminant particles from the photo mask or semiconductor wafer.

According to another aspect of the invention, a method for cleaning a photolithographic mask or semiconductor wafer is provided. In one embodiment, the method includes: A method of cleaning a photolithographic mask or semiconductor wafer includes: providing a jetspray nozzle including a water inlet, a gas inlet, a plurality of gas injection nozzles, and a jetspray nozzle outlet; supplying water to the jetspray nozzle; supplying gas to the jetspray nozzle; mixing the gas and water in the jetspray nozzle; and discharging a gas and water jetspray stream from the nozzle onto the photolithographic mask or semiconductor wafer. The jetspray stream comprises a cluster of micro water droplets entrained in the gas having a predetermined size sufficient to dislodge contaminant particles adhered to the surface of the mask or wafer.

BRIEF DESCRIPTION OF THE DRAWINGS

The features of the preferred embodiments will be described with reference to the following drawings where like elements are labeled similarly, and in which:

FIG. 1 graphically illustrates the operation of a jetspray nozzle according to the present invention;

FIG. 2 shows a graph of a preferred water cluster droplet size distribution versus percent volume according to the present invention;

FIG. 3 shows a cross-sectional view of the jetspray nozzle of FIG. 1;

FIG. 4 shows a top view schematic diagram of one embodiment of a flow mixing baffle and gas injection nozzle arrangement of the jetspray nozzle of FIG. 1;

FIG. 5 shows a schematic diagram of one embodiment of a gas injection nozzle arrangement of the jetspray nozzle of FIG. 1;

FIG. 6 shows a graph of gas flow rate versus water droplet size according to the present invention;

FIG. 7 shows a graph of particle removal efficiency versus gas flow rate according to the present invention; and

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FIG. 8 shows a detailed side view of the flow mixing baffle of the jetspray nozzle of FIG. 1.

All drawings are schematic and are not drawn to scale.

DETAILED DESCRIPTION

This description of illustrative embodiments is intended to be read in connection with the accompanying drawings, which are to be considered part of the entire written description. In the description of embodiments disclosed herein, any reference to direction or orientation is merely intended for convenience of description and is not intended in any way to limit the scope of the present invention. Relative terms such as "lower," "upper," "horizontal," "vertical," "above," "below," "up," "down," "top" and "bottom" as well as derivative thereof (e.g., "horizontally," "downwardly," "upwardly," etc.) should be construed to refer to the orientation as then described or as shown in the drawing under discussion. These relative terms are for convenience of description only and do not require that the apparatus be constructed or operated in a particular orientation. Terms such as "attached," "affixed," "connected" and "interconnected," refer to a relationship wherein structures are secured or attached to one another either directly or indirectly through intervening structures, as well as both movable or rigid attachments or relationships, unless expressly described otherwise. Moreover, the features and benefits of the invention are illustrated by reference to the preferred embodiments. Accordingly, the invention expressly should not be limited to such preferred embodiments illustrating some possible non-limiting combination of features that may exist alone or in other combinations of features; the scope of the invention being defined by the claims appended hereto.

Through testing, the inventors have determined that combining deionized water with a pressurized gas in a specially-configured jetspray nozzle described herein produces a high energy focused stream comprising a cluster of micro water droplets entrained in the gas that have a predetermined size capable of producing sufficient force to dislodge inorganic contaminant particles adhered to the surface of the photo mask. The operating principle behind the jetspray nozzle for cleaning the photo mask is illustrated in FIG. 1. A specially-configured jetspray nozzle **20** is supplied with and combines a relatively small amount of deionized water **22** with a high pressure inert or pure gas **23**. The deionized water **22** is essentially atomized by the sonic effect in jetspray nozzle **20** by the high pressure gas **23** to produce a concentrated high energy jetspray stream **24** comprising a mixture of gas **23** with clustered water droplets **48** entrained therein. The jetspray stream **24** consists primarily of gas **23** with a smaller amount of clustered water droplets **48**. Accordingly, in one embodiment, the volume of gas **23** in the jetspray stream **24** is then directed onto a surface **27** of a photo mask **26** which includes patterned opaque surface features **25** that may include sub-resolution assist features (SRAF) and other features/structures used in conventional and phase-shift photo masks. The water droplets **48** have a force $F = \frac{1}{2}mv^2$; wherein m = mass of droplet and v = velocity of the droplet. The transverse force produced by the water parallel to the surface **27** of mask **26** droplets **48** is sufficient to overcome forces of adhesion or attraction between the contaminant particle **21** and mask **26** for effective cleaning.

An ideal or target water droplet **48** size of 10 microns has been determined to be most effective. However, this droplet size alone is difficult to produce consistently in actual practice. It was further determined through testing that a jetspray stream having a deionized water droplet **48** size distribution of 85% less than about 30 microns effectively removes con-

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taminant particles **21** from the surface **27** of photo mask **26** without seriously damaging the patterned mask surface features. As shown in FIG. 2, this size distribution contains a peak size distribution of about 14% by volume of water droplets **48** of the 10 micron size range which was proven to

generate sufficient transverse force (with respect to the surface of the photo mask) to effectively remove contaminant particles from the mask during the jetspray cleaning process. FIG. 3 schematically illustrates an embodiment of a jetspray nozzle **20** according to the present invention. Jetspray nozzle **20** has a centerline CL which defines a vertical axis VA extending through the centerline of the nozzle from top to bottom as shown, and a horizontal axis HA disposed perpendicular to the vertical axis. Jetspray nozzle **20** includes at least one water supply inlet **50** for supplying water **22** to the nozzle. Water supply inlet **50** may be a tube having a tubular shape in some embodiments, and preferably extends through at least a portion of jetspray nozzle **20** and communicates with cavity **29** as further described herein. In one embodiment, the water **22** is preferably deionized water. Water supply inlet **50** is preferably located at the center and top of nozzle **20**. In one embodiment, water supply inlet **50** is preferably aligned concentrically with the centerline CL and vertical axis VA of jetspray nozzle **20**. In some embodiments, water supply inlet **50** is preferably sized to allow a flow rate of about 100-200 ml/minute of water **22** to be received by jetspray nozzle **20**.

Jetspray nozzle **20** further preferably includes at least one gas supply inlet **28** for supplying a pure or inert gas **23** to the jetspray nozzle, and more preferably may include a plurality of gas supply inlets for evenly feeding the gas to the jetspray nozzle. Gas **23** may be any suitable pure or inert gas such as without limitation N₂ (nitrogen), XCD[®]A (Extreme Clean Dry Air) reticle purge gas available from Entegris Incorporated, etc. As shown in FIG. 3, gas inlet **28** connects to a plurality of branches **33** for further distributing the gas **23** throughout the jetspray nozzle **20** as further described herein. In one embodiment, branches **33** may include a set of upper branches **32** and a set of lower branches **31** as shown. Preferably, each branch **31**, **32** is terminated in a gas injection nozzle **34**, **39**, respectively, which in one embodiment are cone shaped as shown. In one embodiment, injection nozzles **39** define an upper set of nozzles and injection nozzles **34** define a lower set of nozzles as further explained herein. In one embodiment, gas injection nozzles **34** and **39** are concentrically arranged with respect to the centerline CL of jetspray nozzle **20**. Gas injection nozzles **34**, **39** preferably have a gradually decreasing internal diameter smaller than the diameter of the branches **31**, **32** supplying gas **23** to the nozzles to increase the velocity of the gas. Gas injection nozzles **34**, **39** also each preferably have a discharge outlet **35** having a reduced diameter **38** which also is preferably smaller than the supply branches **31**, **32** for the same reason. In one embodiment, the diameter **38** of discharge outlets **35** may be about 0.1 to 0.3 mm for producing the desired water droplet **48** size when the gas **23** is mixed with the water **22**.

With continuing reference to FIG. 3, jetspray nozzle **20** defines an internal mixing cavity **29** for mixing the water **22** with gas **23**. Cavity **29** is further defined by a sloping and converging interior surfaces **51** and **53** of the nozzle. In one possible embodiment, as shown, surface **51** preferably slopes outwards away from centerline CL of jetspray nozzle **20** and surface **53** preferably slopes inwards towards centerline CL to concentrate the gas and water jetspray stream **24** mixture. Preferably, in one embodiment, cavity **29** preferably opens outwards and downwards through the bottom of jetspray nozzle **20** to define a jetspray nozzle outlet **42** for delivering

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the concentrated/focused jetspray stream **24** mixture of gas **23** and deionized water **22** onto the surface **27** of photo mask **26** for cleaning the mask. In one embodiment, jetspray nozzle outlet **42** may have a diameter of about 4 to 6 mm. Preferably, jetspray nozzle outlet **42** may be concentrically aligned with centerline CL of jetspray nozzle **20** as shown. Cavity **29** is in fluid communication with water supply inlet **50** and gas inlet **28** via branches **31**, **32** and nozzle tips **35**. Gas injection nozzles **34**, **39** and water supply inlet **50** preferably terminate at cavity **29** as shown.

In one preferred embodiment, jetspray nozzle **20** is symmetrical in configuration about the centerline CL as shown in FIGS. 3 and 4. Accordingly, in this embodiment, water supply inlet **50**, gas injection nozzles **34** and **39**, and jetspray nozzle outlet **42** are all arranged concentrically with respect to the centerline CL of the jetspray nozzle for even distribution, mixing, and discharge of the gas **23** and water **22** stream from the jetspray nozzle. In other embodiments, one or more of these features may be asymmetrically arranged with respect to centerline CL of jetspray nozzle **20** so long as uniform mixing and delivery of the gas **23** and water **22** droplets **48** is provided.

Cavity **29** further includes an internal flow mixing baffle **30** disposed in the cavity for combining the water **22** with gas **23**. In one possible embodiment, as best shown in FIGS. 3 and 8, mixing baffle **30** may be cone shaped and symmetrical in configuration (shown in cross section in FIG. 3 with left portion omitted to better show gas nozzles). Baffle **30** may be solid or hollow, or a combination of both. In one embodiment, baffle **30** preferably includes a conical tip **36** which is at least partially positioned inside water inlet **22** as shown or relatively proximate to the outlet of inlet **22** and a sloping radial sidewall **52** (see FIG. 8). Baffle **30** is preferably positioned within cavity **29** to form an annular gap **37** between gas nozzles **34**, **39** and sidewall **52** of baffle **30**. This creates a restricted space to provide uniform distribution and thorough mixing of water **22** into the gas **23** flow for producing entrained water droplet **48** clusters in the gas. In some embodiments, annular gap **37** may be about 0.3 to 0.7 mm. The conical shape of baffle **30** and tip **36** further serves to separate and uniformly distribute the water **22** over the surfaces of the baffle to enhance uniform mixing with the gas **23**.

With reference to FIGS. 3-5, gas injection nozzles **34**, **39** are configured and arranged to form a double row of gas nozzles with upper nozzles **39** being disposed vertically above lower nozzles **34**. FIG. 4 shows a schematic top view of mixing baffle **30**, with one possible preferred arrangement of lower and upper gas injection nozzles **34**, **39**. In this embodiment, jetspray nozzle may be generally circular in configuration when viewed from the top; however, other suitable configurations may be used for the jetspray nozzle. As shown, lower and upper gas injection nozzles **34**, **39** are preferably distributed with even spacing around the circumference of jetspray nozzle **20** and baffle **30** to provide uniform injection and distribution of gas **23** into cavity **29** of jetspray nozzle. Accordingly, in one embodiment, upper gas injection nozzles **39** define a first upper row or ring **40** of gas nozzles and lower gas injection nozzles **34** define a second lower row or ring **41** of gas nozzles both concentrically arranged around the vertical axis VA or centerline of jetspray nozzle **20**. The upper ring **40** of nozzles **39** is spaced vertically apart from the lower ring **41** of nozzles **34** in one embodiment as shown. Also preferably, in one embodiment, upper gas injection nozzles **39** are preferably radially offset from lower gas injection nozzles **34** by a radial angle **A3** to further enhance uniform injection of gas **23** into jetspray nozzle **20** and mixing with the water **22**.

In one embodiment as shown, a total of 16 gas injection nozzle may be provided comprised of 8 upper nozzles **39** and **8** lower nozzles. In this embodiment, angle **A3** may be about 22.5 degrees. It will be appreciated that other numbers of gas injection nozzles may be used so long as uniform mixing between the water **22** and gas **23** may be achieved.

As shown in FIG. 5, in one embodiment, upper gas injection nozzles **39** may be asymmetrically oriented with respect to lower gas injection nozzle **34** such that each set of nozzles are angled downwards at a different angle with respect to the vertical axis VA and horizontal axis HA of jetspray nozzle **20**. Preferably, upper gas injection nozzles **39** are oriented at a sharper or steeper angle with respect to the horizontal axis HA than lower gas injection nozzles **34**. Since upper nozzles **39** inject gas **23** at a higher location on cone-shaped mixing baffle **30**, the sharper angle directs the gas more vertically to minimize any backflow towards the water supply inlet **50**. In one representative embodiment, upper gas nozzles **39** are disposed at angle **A2** to the horizontal axis of between about 60-75 degrees and lower gas nozzles **34** are disposed at angle **A1** to the horizontal axis of between about 40-55 degrees. Other suitable angles **A1**, **A2** may be used so long as good mixing between the water **22** and gas **23** may be achieved and gas backflow towards water supply inlet **50** is minimized.

It will be appreciated that uniform injection and distribution of gas **23** into jetspray nozzle **20** is necessary for producing the desired water droplet **48** size distribution described herein.

Jetspray nozzle **20** may be made of any suitable material, such as for example without limitation polymers, and preferably Teflon (e.g. Teflon-PFA, Teflon-PTFA, etc.) in some embodiments.

The operation of jetspray nozzle **20** will now be described. Tests were conducted to optimize the flow and pressure of the deionized water **22** and gas **23** for achieving the desired water droplet **48** size distribution, which in one embodiment is preferably 97% droplet **48** size less than 100 microns, and more preferably 85% droplets **48** less than 30 microns. The water droplet **48** size is proportional to the diameter of the water supply inlet **50**, and the water supply pressure and flow rate. The droplet **48** speed or velocity (v) is proportional to the pressure of the gas supply **23** and inversely proportional to the diameter **38** of the gas injection nozzle outlets **35**.

FIG. 6 is a chart which shows the results of foregoing tests performed to optimize gas flow rate and deionized water droplet **48** size distribution produced by jetspray nozzle **20**. The jetspray outlet **42** diameter, gas injection nozzle diameters **38**, and gap **37** sizes used for the test were as described above. Water **22** supply flow rate was controlled to about 100-200 ml/minute by varying the water supply pressure. Gas **23** supply pressure was varied from a minimum of about 70 psi to higher pressures to produce gas flow rates varying from about 30-100 liters/minute. As shown in FIG. 6, at a minimum gas flow rate of about 60 liters/minute which corresponded to a deionized water flow rate of 150 ml/minute, the desired 10 micron size water droplets **48** were produced. This produced the desired distribution of 85% droplets **48** less than 30 microns with a 14% volume of the 10 micron size water droplets **48** (shown in FIG. 2). This distribution provided the desired particle removal efficiency as further explained herein.

The operational arrangement of jetspray nozzle and photo mask **26** for the jetspray cleaning process will now be described. Referring again to FIG. 1, jetspray nozzle **29** may be mounted in the front end of a programmable swivel arm around a rotationally movable chuck holder. The photo mask is put onto the rotatable chuck holder (also Z-axis movable).

The jetspray nozzle is programmable to move in position in any combination of 3-dimensional directions including forward and backward above photo mask **26** with full spray coverage of the mask during the jetspray cleaning process. Movement of the jetspray nozzle may be controlled by a programmable logic controller executing appropriately configured control logic. This arrangement allows jetspray nozzle **20** to be articulated over and positioned above a plurality of various portions of the photo mask for cleaning. In one embodiment, the jetspray nozzle **20** is preferably positioned so that the jetspray nozzle outlet **42** is approximately 10 mm above the surface **27** of photo mask **26** (i.e. cleaning process gap). Photo mask **26** may be attached to a chuck (not shown) and rotated beneath jetspray nozzle **20** during the cleaning process (as indicated by the rotational arrow shown in FIG. 1). The jetspray nozzle **20** may therefore remain temporarily stationary in one of many possible positions while the photo mask **26** is rotated. In one representative embodiment, a rotational chuck speed of about 150 rpm may be used.

The particle removal efficiency (PRE) of jetspray nozzle **20** was determined using the foregoing operational setup, jetspray nozzle having the two-level gas injection nozzles **34**, **39** arrangement, and deionized water and gas flow rates/pressures described herein according to the present invention. A standardized testing procedure used to measure photo mask cleaning PRE was followed. This standard test included using 100 nm size SiN4 particles as the contaminant which were disposed on the surface of a photo mask. A minimum target PRE of 90% was established which is considered good PRE performance when measuring the effectiveness for photo mask cleaning processes. At a PRE of 90% or above, a sufficient number of contaminant particles are removed from the surface of the photo mask so that any remaining particles do not generally interfere with the photolithography process and proper patterning of the photoresist on the wafer. A maximum of 10 minutes spray time was used during which time the photo mask with 100 nm test contaminant particles were exposed to the concentrated cleaning jetspray of clustered deionized water. Exceeding the 10 minute threshold increases the probability of damaging the pattern on the photo mask.

The results of the foregoing standardized PRE tests are graphically shown in FIG. 7. At a minimum gas **23** flow rates of about 50 liters/minute, the minimum target 90% PRE was obtained without mask pattern damage when the photo mask **26** was cleaned with clustered deionized water for 10 minutes using a jetspray stream **24** having 85% droplets **48** less than 30 microns in size. As shown in FIG. 7, gas flow rates of greater than 50% produced increasingly higher levels of PRE. The N45 process technology particle count was less than 5 particles each, which is comparable in mask cleaning efficiency to known SC1 or DiH2 cleaning processes augmented by Megasonic waves. In addition, the jetspray cleaning process described herein performed well beyond the N45 process technology (i.e. N32) with no pattern damage and SRAF damage performance comparable with conventional Megasonic cleaning processes. Advantageously, the foregoing PRE performance using the jetspray nozzle and cleaning process according to the present invention was obtained using only deionized water without the addition of any chemicals as required in the prior known photo mask cleaning processes described herein, thereby avoiding chemical usage and related possible precipitated defect formation on the photo mask attributed to ammonia-based prior art processes.

Although the jetspray nozzle and method according to the present invention has been described herein for use in photo mask cleaning, the jetspray nozzle **20** may be used to clean

other components involved in semiconductor fabrication. In one embodiment, for example, the jetspray nozzle **20** and method may be used to clean a semiconductor wafer. The wafer cleaning application may use only one of the upper row or ring **40** of gas nozzles **39** or lower row or ring **41** of gas nozzles **34** in some applications because the main purpose of jetspray cleaning on wafer application is for the final rinse process. A single row of nozzles in the jetspray nozzle head is powerful enough on chemical residue and contamination removal where the water droplet **48** uniformity is not as much of a concern as in photomask cleaning.

While the foregoing description and drawings represent preferred or exemplary embodiments of the present invention, it will be understood that various additions, modifications and substitutions may be made therein without departing from the spirit and scope and range of equivalents of the accompanying claims. In particular, it will be clear to those skilled in the art that the present invention may be embodied in other forms, structures, arrangements, proportions, sizes, and with other elements, materials, and components, without departing from the spirit or essential characteristics thereof. One skilled in the art will further appreciate that the invention may be used with many modifications of structure, arrangement, proportions, sizes, materials, and components and otherwise, used in the practice of the invention, which are particularly adapted to specific environments and operative requirements without departing from the principles of the present invention. In addition, numerous variations in the preferred or exemplary methods and processes described herein may be made without departing from the spirit of the invention. The presently disclosed embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being defined by the appended claims and equivalents thereof, and not limited to the foregoing description or embodiments. Rather, the appended claims should be construed broadly, to include other variants and embodiments of the invention, which may be made by those skilled in the art without departing from the scope and range of equivalents of the invention.

What is claimed is:

1. A jetspray nozzle for cleaning a photolithographic mask or semiconductor wafer comprising:

a water supply inlet;

a gas supply inlet;

a first row of gas injection nozzles communicating with the gas supply inlet; the first row of gas injection nozzles arranged to form a ring of radially spaced apart nozzles that are concentrically arranged about an axial centerline of the jetspray nozzle;

an enlarged mixing cavity defining a jetspray nozzle outlet, the cavity being radially larger than the water supply inlet; and

a flow mixing baffle disposed in the cavity, the mixing baffle being configured and arranged to combine gas and water for delivering a gas-water mixture from the nozzle outlet for removing contaminant particles from the photolithographic mask or wafer;

wherein the first row of injection nozzles are arranged and configured to discharge gas into the enlarged mixing cavity towards the baffle.

2. The jetspray nozzle of claim **1**, further comprising a second row of gas injection nozzles spaced above or below the first row of gas injection nozzles and communicating with the gas supply inlet, the second row of gas injection nozzles

arranged to form a ring of radially spaced apart nozzles that are concentrically arranged about the axial centerline of the jetspray nozzle, wherein the first and second rows of gas injection nozzles are arranged and configured to discharge gas into the enlarged mixing cavity towards the baffle.

3. The jetspray nozzle of claim **2**, wherein the gas injection nozzles in the second row are radially offset from the gas injection nozzles in the first row by a radial angle such that the gas nozzles in the first and second rows are not radially aligned.

4. The jetspray nozzle of claim **3**, wherein the radial angle is about 22.5 degrees.

5. The jetspray nozzle of claim **2**, wherein the gas injection nozzles in the first row are disposed at an angle to a horizontal axis extending through the jetspray nozzle that is different than a corresponding angle of gas nozzles in the second row to the horizontal axis.

6. The jetspray nozzle of claim **1**, wherein the flow mixing baffle has a conical shape.

7. The jetspray nozzle of claim **6**, wherein the baffle includes a tip which is positioned concentrically with respect to the water supply inlet.

8. The jetspray nozzle of claim **1**, wherein the gas injection nozzles are disposed at an angle to a horizontal axis extending through the jetspray nozzle.

9. The jetspray nozzle of claim **1**, wherein the jetspray nozzle is symmetrical in shape and the water supply inlet and the jetspray outlet are both concentrically aligned with a centerline defined by the jetspray nozzle.

10. A jetspray nozzle for cleaning a photolithographic mask or semiconductor wafer comprising:

a water supply inlet;

a gas supply inlet;

a first row of lower gas injection nozzles communicating with the gas supply inlet and being arranged concentrically about an axial centerline defined by the jetspray nozzle;

a second row of upper gas injection nozzles communicating with the gas supply inlet and being arranged concentrically about the centerline of the jetspray nozzle, the first and second row of gas injection nozzles being axially spaced apart and each forming a ring of radially spaced apart nozzles that are concentrically arranged about an axial centerline of the jetspray nozzle;

an enlarged mixing cavity defining a jetspray nozzle outlet, the cavity being radially larger than the water supply inlet; and

a conical flow mixing baffle disposed in the cavity, the mixing baffle being configured and arranged to combine gas and water for delivering a gas-water mixture from the nozzle outlet for removing contaminant particles from the photolithographic mask or wafer;

wherein the first and second rows of injection nozzles are arranged and configured to discharge gas into the enlarged mixing cavity towards the baffle.

11. The jetspray nozzle of claim **10**, wherein the water inlet and the jetspray nozzle outlet are concentrically arranged with respect to the centerline of the jetspray nozzle.

12. The jetspray nozzle of claim **10**, wherein the upper gas injection nozzles are radially offset from lower gas injection nozzles by a radial angle such that the upper and lower nozzles do not lie in radial alignment.

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13. The jetspray nozzle of claim **12**, wherein the radial angle is about 22.5 degrees.

14. The jetspray nozzle of claim **10**, wherein the upper gas injection nozzles are disposed at a different angle to a horizontal axis extending through the jetspray nozzle than the lower gas injection nozzles.

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15. The jetspray nozzle of claim **10**, wherein the water supply inlet is aligned with a tip of the flow mixing baffle and the upper and lower gas injection nozzles are positioned adjacent a sidewall of the flow mixing baffle.

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